GRB and SN
in the light of Swift

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Collapsar & SN :

a direct link - at least sometimes

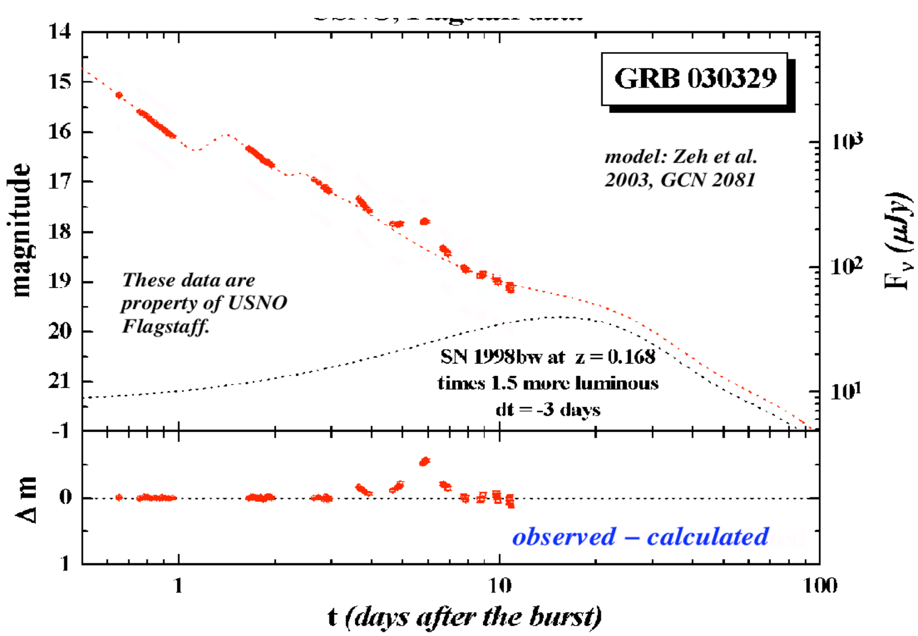
- Core collapse of star w. $M_t \sim 30\ M_{sun}$
  $\rightarrow$ BH + disk (if fast rot.core)
  $\rightarrow$ jet (MHD? baryonic? high Γ,
  + SNR envelope eject (always?)
- 3D hydro simulations (Newtonian SR) show that baryonic jet w. high G can be formed/escape
- SNR: not seen *numerically* yet (**but:** strong suggestive observations, e.g. late l.c. hump + reddening; and ..
- ***Direct*** observational (spectroscopic) detections of GRB/ccSN

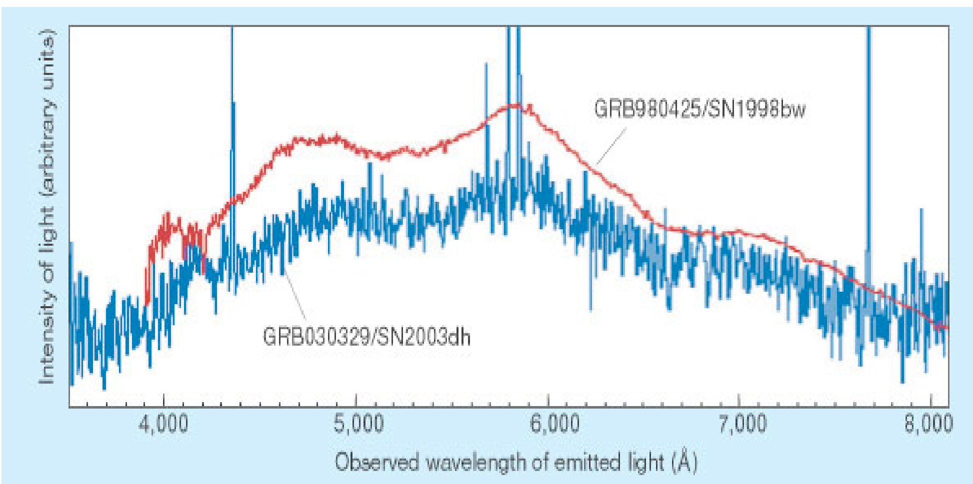
Collapsar & SN ANIMATION

Credit: Derek Fox & NASA

Collapsar & ccSN :

GRB 030329 - SN 2003dh & others



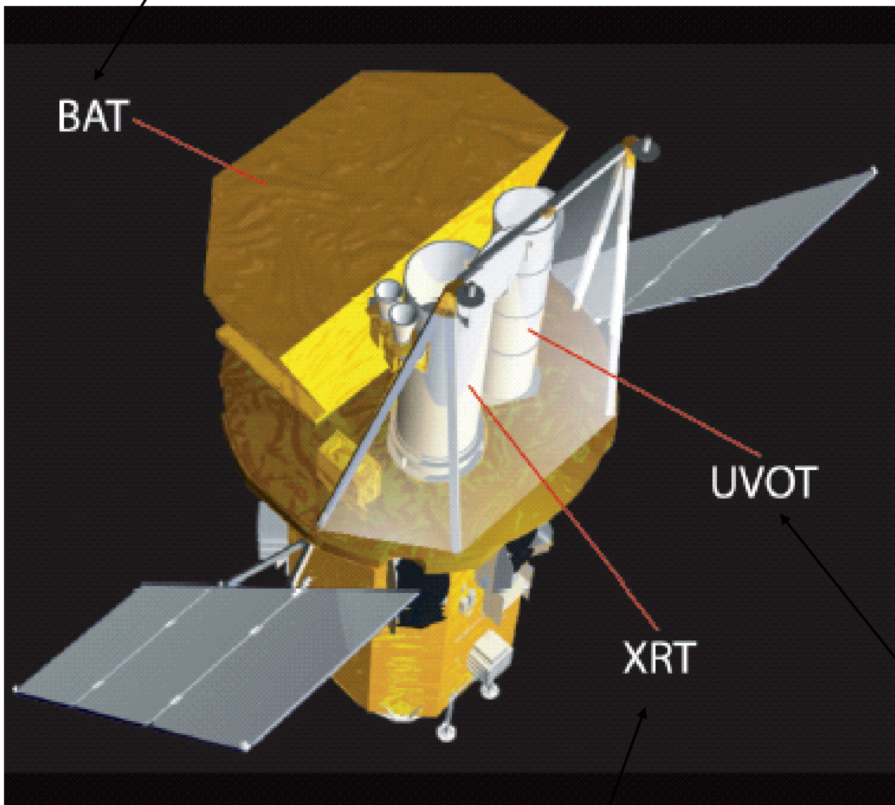


- 2nd Nearest "unequivocal" cosmological GRB: **z=0.17**
- **GRB-SN association**: **"strong"**
- Fluence: 10^{-4} erg cm^{-2} ,
  among highest in BATSE,
  but t_γ~30s, nearby; $E_{g,iso}$~$10^{50.5}$erg: ~typical,
- $E_{SN2003dh,iso}$ ~$10^{52.3}$ erg
  ~ $E_{SN1998bw,iso}$ («grb980425)
  $v_{sn,ej}$ ~0.1c (→ "hypernova")
- GRB-SN simultaneous? at most:
  < 2 days off-set (from opt. lightcurve)
  (→ i.e. not a "supra-nova")
- But: might be 2-stage (<2 day delay) *- NS-BH collapse ?
  → ν predictions may test this !
- Some others:
  GRB 031203/SN2003lw;
  - GRB 060218/SN2006aj; ...

Mészáros, grb-sn07

BAT: Energy Range: 15-150kev
FoV: 2.0 sr
Burst Detection Rate: 100 bursts/yr

SWIFT



Three instruments

Gamma-ray, X-ray and optical/UV

Slew time: 20-70 s !

>95% of triggers yield XRT det
>50% triggers yield UVOT det.

UVOT: Wavelength Range: 170-650nm

XRT: Energy Range: 0.2-10 keV

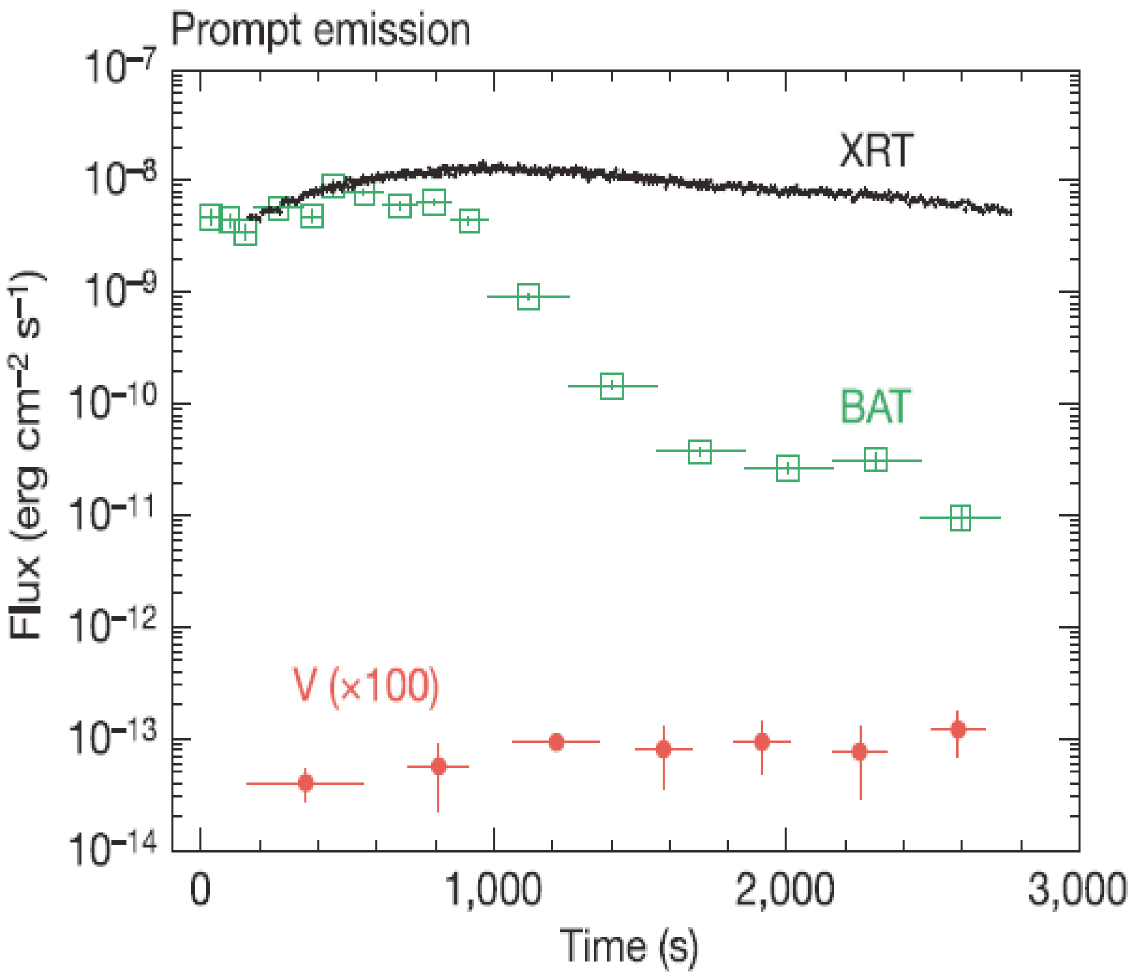
Launched Nov 04

GRB 060218 / SN 2006aj

Campana et al, 2006, Nature 442:1006;
Waxman, Meszaros & Campana astro-ph/0702450)

- Long(est) BAT T90 = 2100 s duration
- XRT after 100 s, rising to max at ~1000s, followed by steep decay, then PL decay
- UVOT brightening to UV plateau @ 30ks
  and later O plateau @ 40ks, decay to minimum @200ks, rebrightening @700ks
- XR non-thermal plus increasing BB component which dominates before the steep decay @1000s (kT_{BB} ~ 0.17 keV)

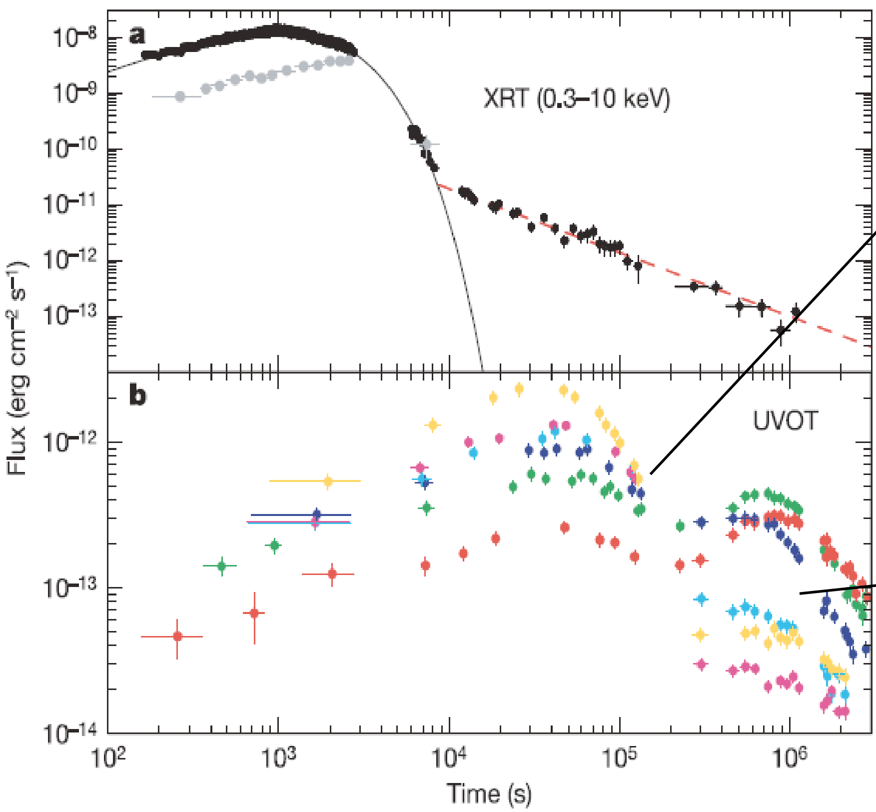
GRB060218/SN2006aj –initial explosion



- An unusually long, smooth burst, T_{90}~2100±100 s
- Low luminosity, low energy : E_{iso}~6x10^{49} erg
- z=0.033, second nearest GRB

Campana et al. 2006

Subsequent evolution—SN emerges



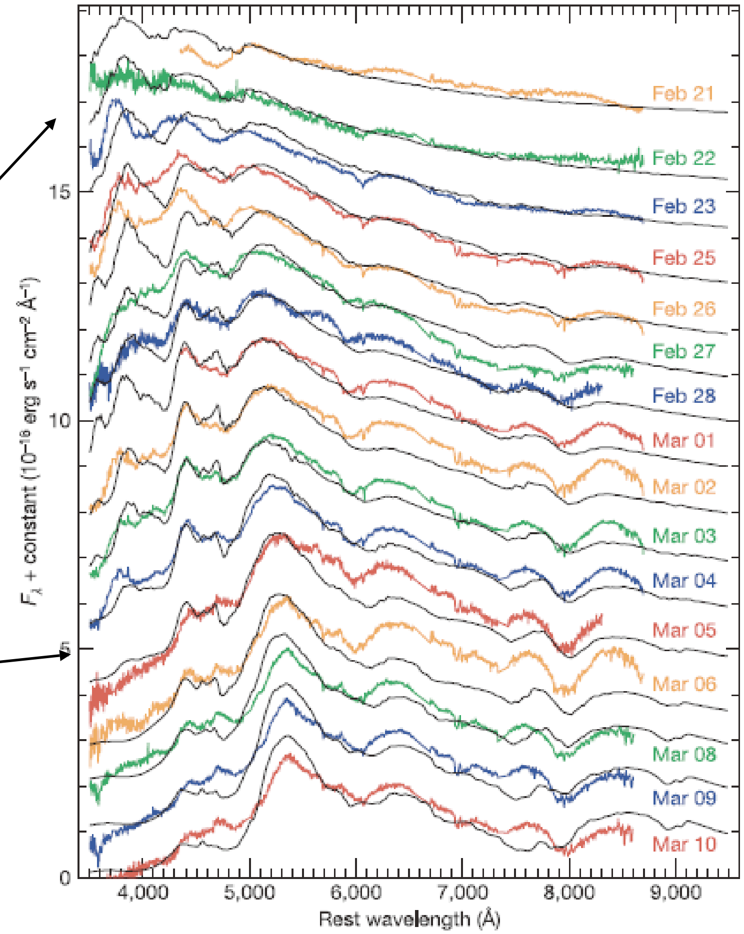
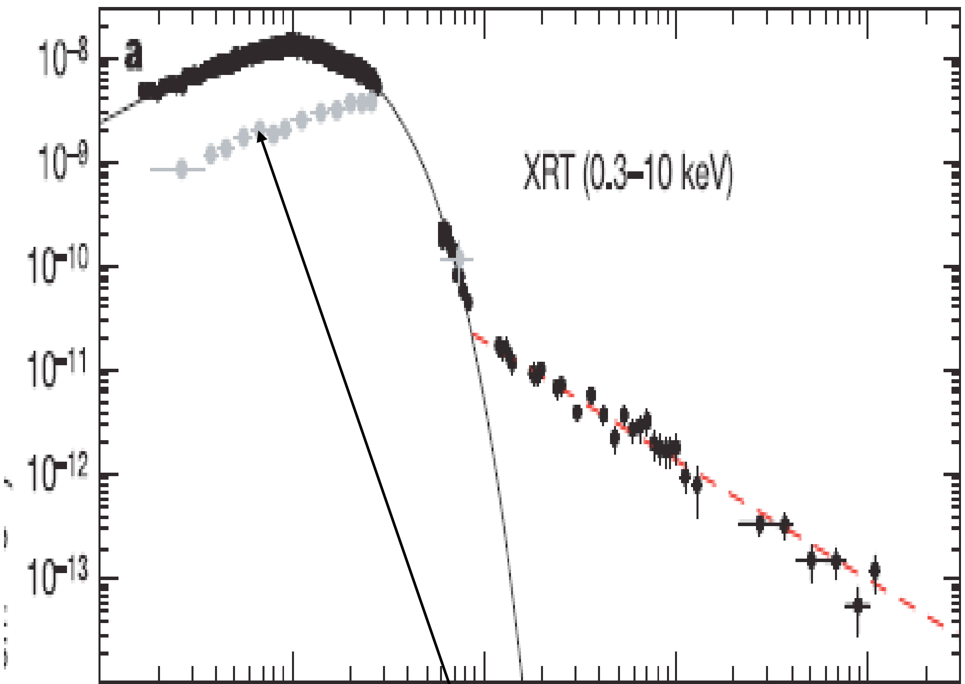


Figure 1 | Spectra of SN 2006aj and synthetic fits. The observed spectra of

Campana et al. 2006

Mazzali et al. 2006

A closer look at the XRT spectrum



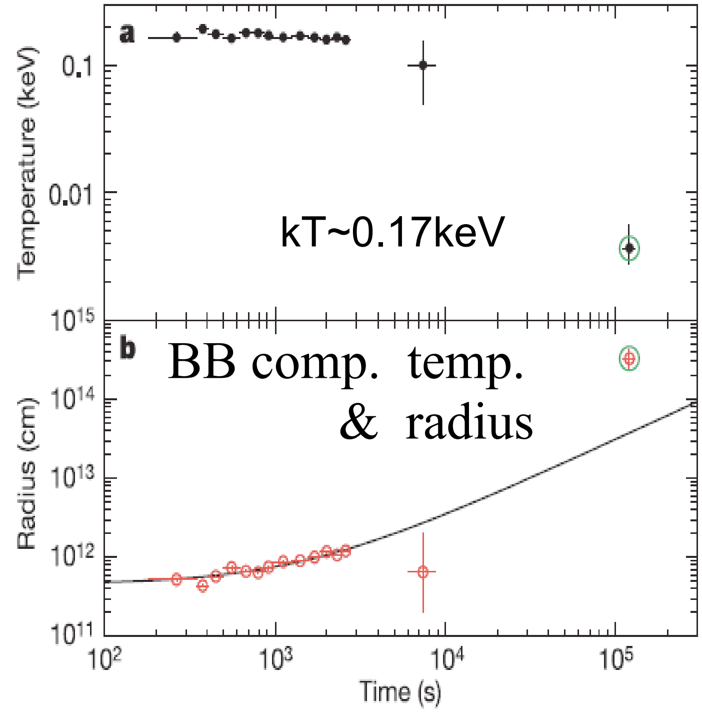


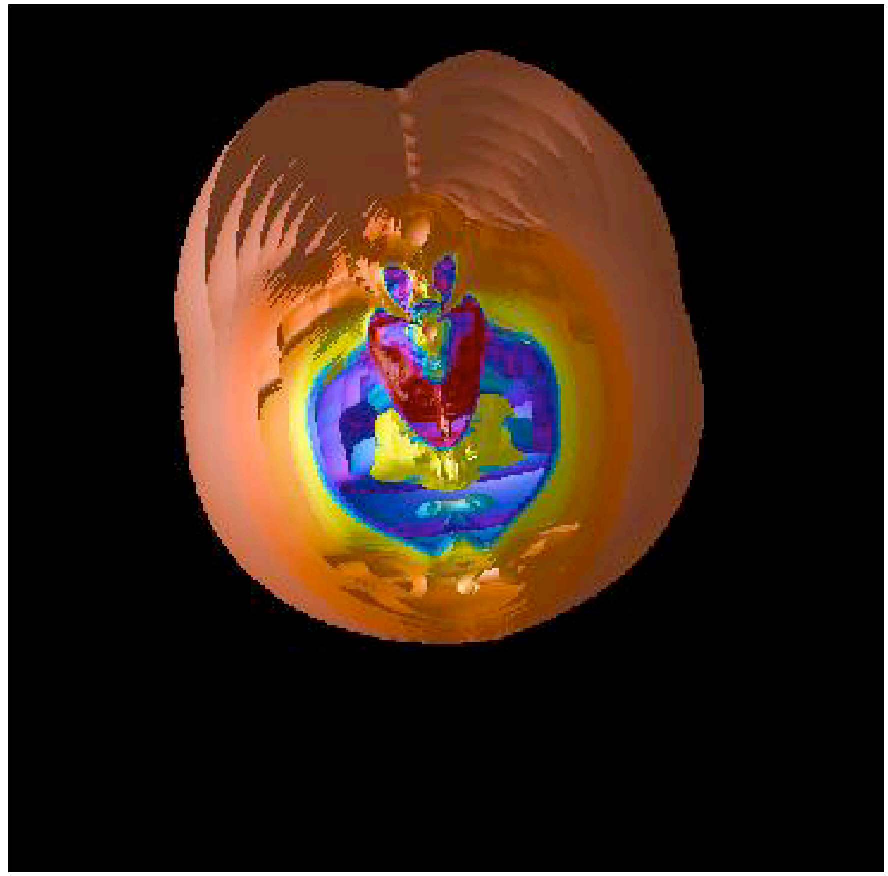
Figure 3 | Evolution of the soft thermal component temperature and radius. a, Evolution of the temperature of the soft thermal component. The

Contribution of a fitted **black-body component** to the 0.3-10KeV flux

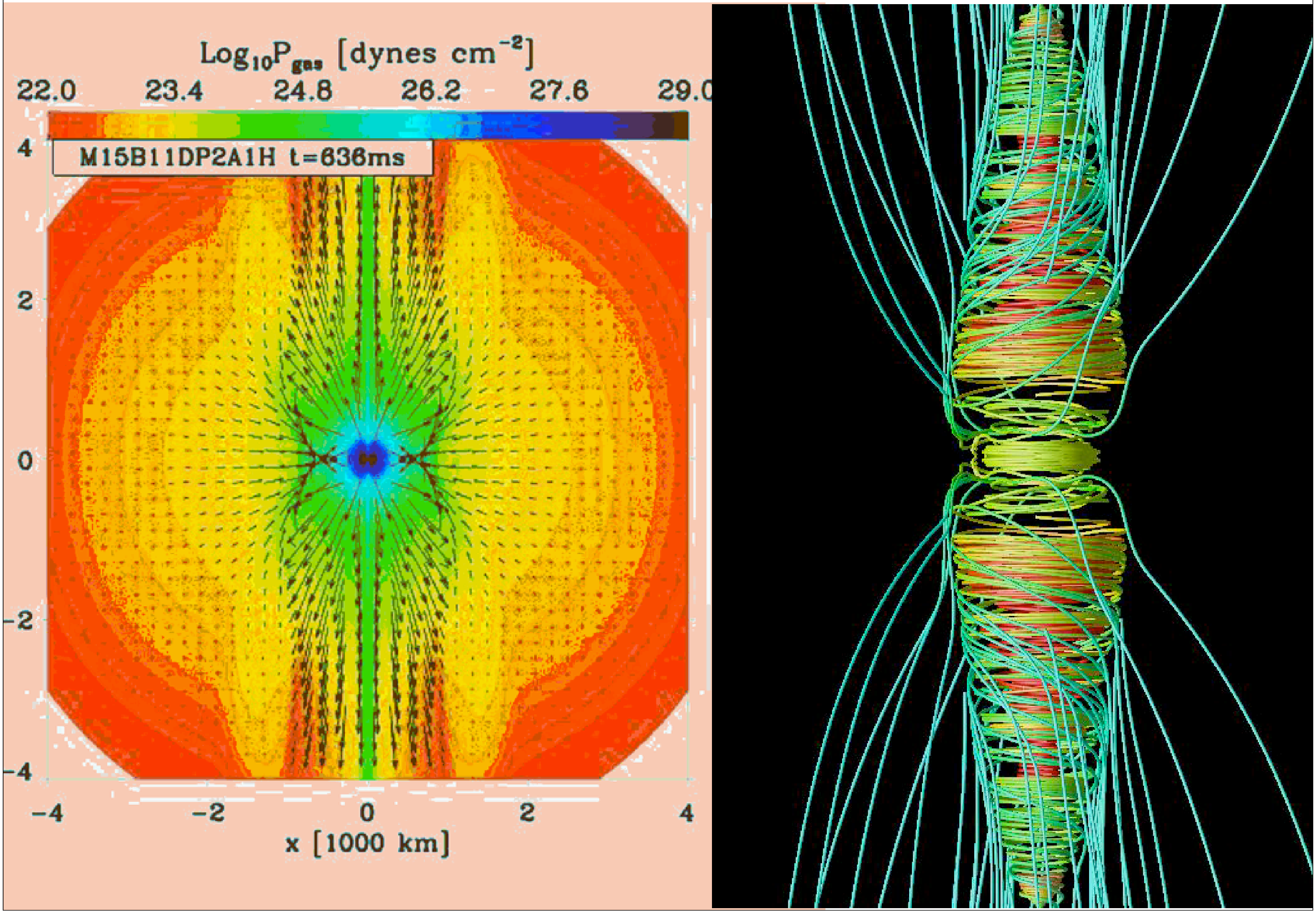
Constitute 20% of the total XRT fluence

Hints: anisotropic ccSNe

- Rotation may play a crucial role not only in collapsar GRB/SNe (McFadyen & Woosley 99)
- But even in "normal" ccSNe explosions (e.g. Burrows et al, 07, astro-ph/0610175 →)
- Shock can appear "jet-like", etc (e.g.also polariz. obs. of SNIc)
- Jet & MHD effects could be dominant (e.g. Nomoto @Venice,..)



Hints: magneto-rotat. driven SN & PNS- Burrows, et al astroph/07



(1) Thermal XR Component: GRB060218/SN2006aj

- Interpreted as **break-out** of an ***anisotropic***, ***semi-relativistic, radiation-mediated*** **shock** from opt. thick ***stellar wind*** (Campana et al 06, Nat. 442:1006; Waxman, Mészáros & Campana astro-ph/0702450)
- ***Anisotropy*** is a crucial ingredient: timescale $\sim 10^3$ s is attributed to ***sideways*** pattern expansion speed, ***not*** to radial speed.
- Breakout when $\tau_T \sim c/v_s$, ocurring (in the wind) at $\mathbf{R_{ph}} \sim 7\times10^{12}\,(T/0.17\ \mathrm{keV})^{-4/7}\,(E_{th}/10^{49}\ \mathrm{erg})^{3/7}$ cm, for mass loss $dM/dt > 10^{-4}$ Msun/yr when $v_w \sim 10^3$ km/s
- Note : corresponds to mass loss within last day before explosion- no data on such winds
- Anisotropy of semi-relat. shell & wind compatible with & expected from rotation effects (e.g. Burrows et al, aph/0608033, Metzger et al, aph0608682, Burrows et al, aph/0702539, etc

(2) GRB060218 XR afterglow: wind-shell interaction

- Beyond τ_T~1, shock no longer rad-mediated, heats up increasing part of wind, deceleration at t_{dec}~0.06 days, thereafter energy carried by shocked wind plasma → **XR afterglow** due to sync & IC (of same anisotr. shock as the thermal XR), in good agreement with XR obs.
- Early **O/UV**: due to the SN shock heating of the stellar envelope (more usual, isotropic component, ≠ from the anisotr. thermal & afterg XR) - after shock goes through, envelope expands, cools; leads to R~3 10^{14} cm , T~ 3 eV at t~10^5 s
- **Radio:** this model, large opt. depth → ***suppress radio***- need interpret it as ≠ component (involves negligible fraction of total energy)

Critiques

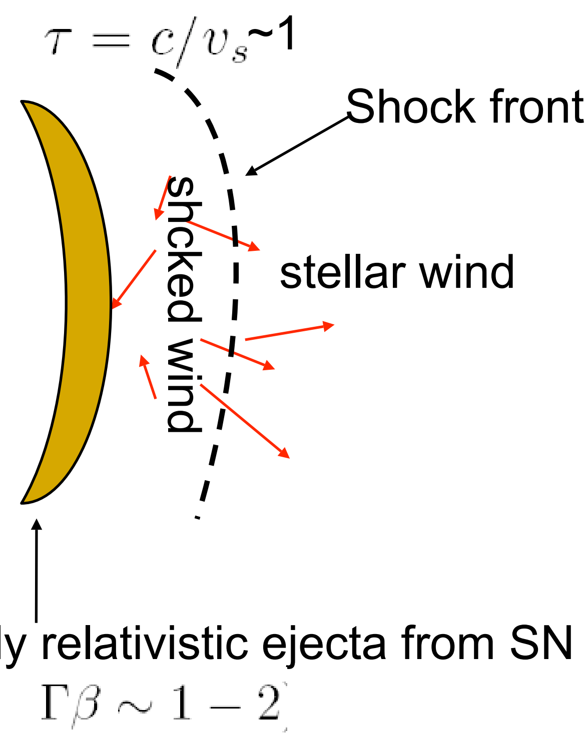
- ***Have been addressed in astro-ph/0702450***
- Ghisellini et al 06: assumed both our XR thermal and UV arise from same shock (they don't) and thought we assumed isotropic XR (we don't)
- Li 06: assumes we need a star radius 100 Rsun (in fact we have a photosphere in the wind, not in the envelope)- wind mass loss not unreasonable, and is completely unconstrained from obs @ 1 day
- Fan et al 06: argue against saying that radio prediction is too high- in fact it is too low. Argue also for different explosion parameters derived from radio obs. (but radio estimates for these vary by large factor, and most energy is in XR, UV, not radio)

Non-thermal gamma-rays in semi-rel. jets:

Bulk-motion Comptonization of thermal x-rays

Wang, Li, Waxman & Meszaros 2006, astro-ph/0608033

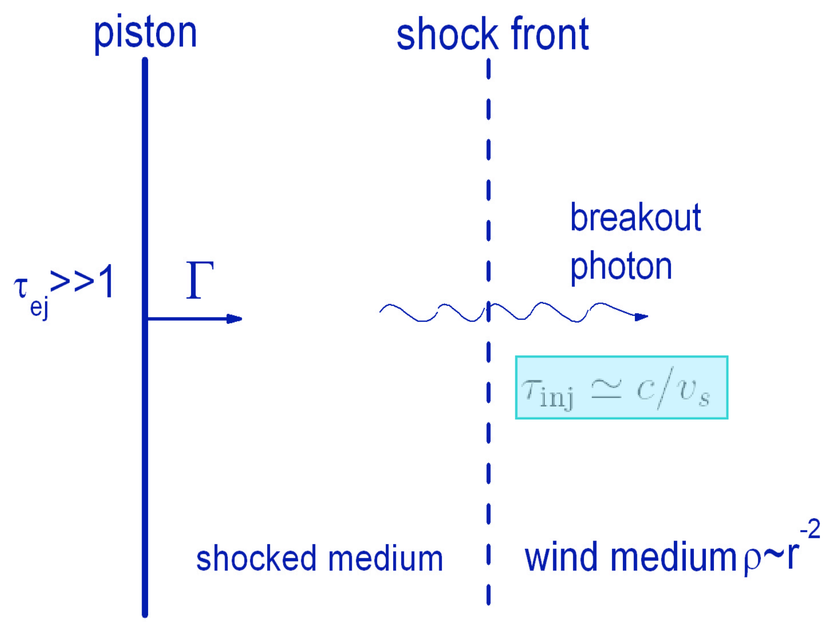
- Non-negligible optical depth ahead of the shock $\tau = c/v_s$
- Some thermal photons are repeatedly scattered by the electrons to increasingly higher energy before they can escape
- "photon acceleration", giving rise to a nonthermal component
- Cold electrons, bulk-motion dominated



similar to "Fermi acceleration"

One-dimension Monte-Carlo Simulation to understand the time-dependent case

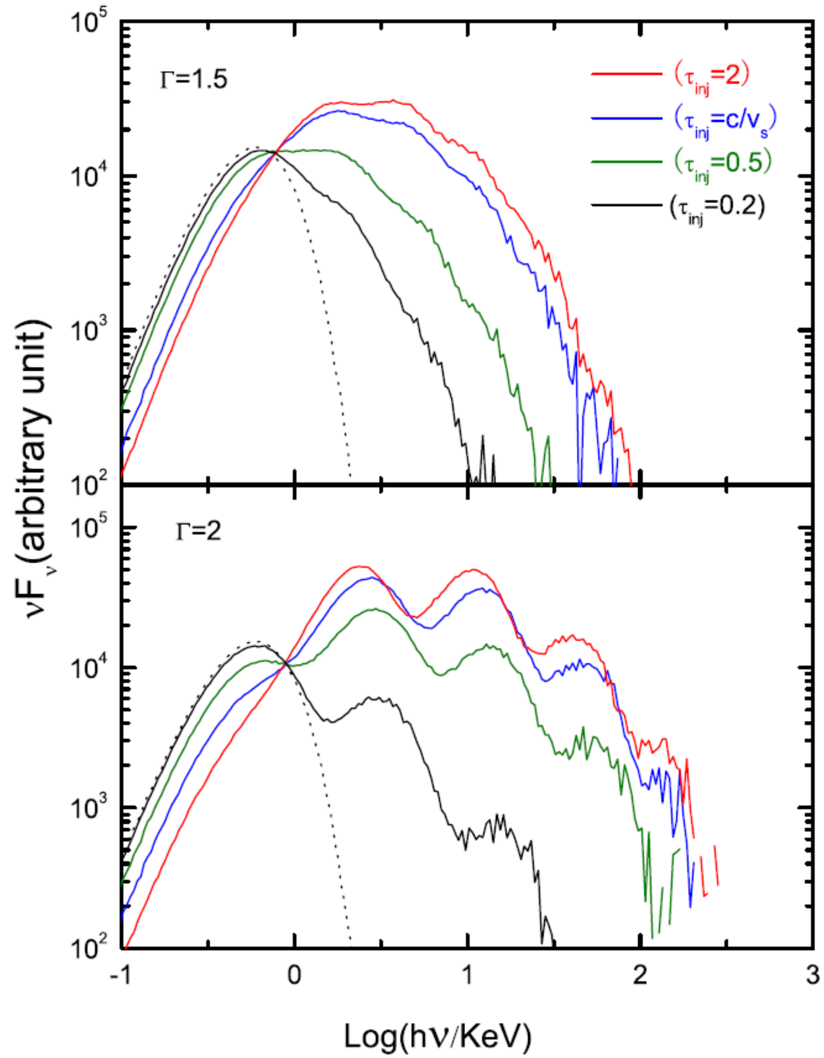
- Picture: three regions structure
- At shock breakout radius (corresponding to $\tau_{\rm inj}$), black-body photons are injected
- Follow the scattering history until the photons come out
- Photon-electron scattering in each of three regions, with energy gain or loss
- Record the energy and arrive time of each photon: Construct the spectrum and arriving time of the escaping photons



Simulation results --- time-integrated spectrum

- 10^6 thermal "seed" photons with kT=0.15KeV (black dotted line)
- Non-thermal component is indeed dominated for mildly relativistic shock
- Note the "humps' are artifact of the one-dimension simulation
- Large Gamma, large peak energy, peak energy could be around a few KeV--- X-ray flash
- Spectrum becomes steeper at higher energies (decreasing tau effect)

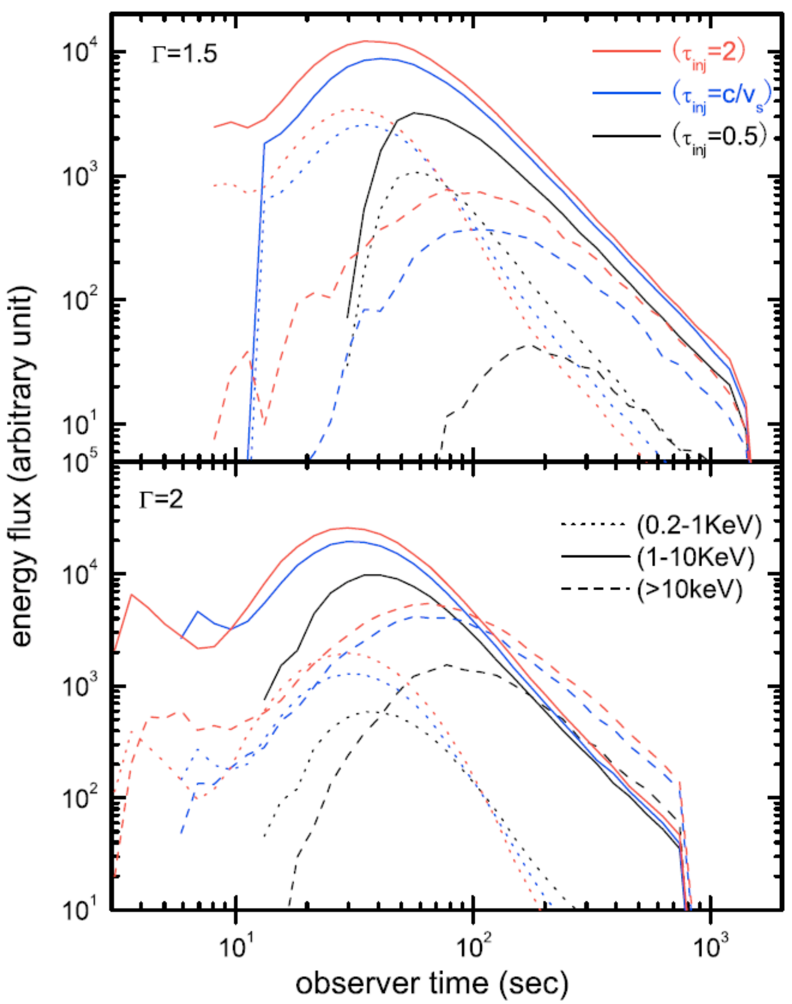
$$\alpha = -\ln\tau / \ln A$$



wind parameters are: $\dot{M} = 10^{-4} M_\odot \mathrm{yr}^{-1}$ and $v_w = 10^8 \mathrm{cms}^{-1}$

Simulation ---arrival time distribution

- higher energy photons delayed
- But the delay time is unimportant compared to ~1000 s duration, which is due to the light travel time effect of a non-spherical SN shock
- This is not the light curve →
- Light curve would result from superposition of the radiation from different regions at various angles (i.e. time offsets, depending on the unknown jet structure) with ≠ Γ and τ_{inj}



Other supernova-GRBs

Table 1: The spectrum of three nearby low-luminosity GRBs

GRB/SN	z	$E_{\gamma,\mathrm{iso}}(\mathrm{erg})$	α	$\varepsilon_c(\mathrm{KeV})$
GRB980425/SN1998bw	0.0085	$8.5 \pm 0.1 \times 10^{47}$	0.45 ± 0.22	~ 200
GRB031203/SN2003lw	0.105	$4 \pm 1 \times 10^{49}$	0.63 ± 0.06	> 190
GRB060218/SN2006aj	0.0331	$6.2 \pm 0.3 \times 10^{49}$	0.45	$\sim 30^{\S}$

- 1) Low-luminosity
- 2) Smooth light curves
- 3) Spectrum: a simple power-law with a high energy cutoff
- Short T_90 duration for GRB980425 and GRB031203: possibly shock breakout from the star envelope (i.e. no optically thick wind)

GRB Precursors

- Sometimes as much as ~100 s gap
- Gap sometimes quite “empty”
- Energy involved few % of main burst

GRB041219A

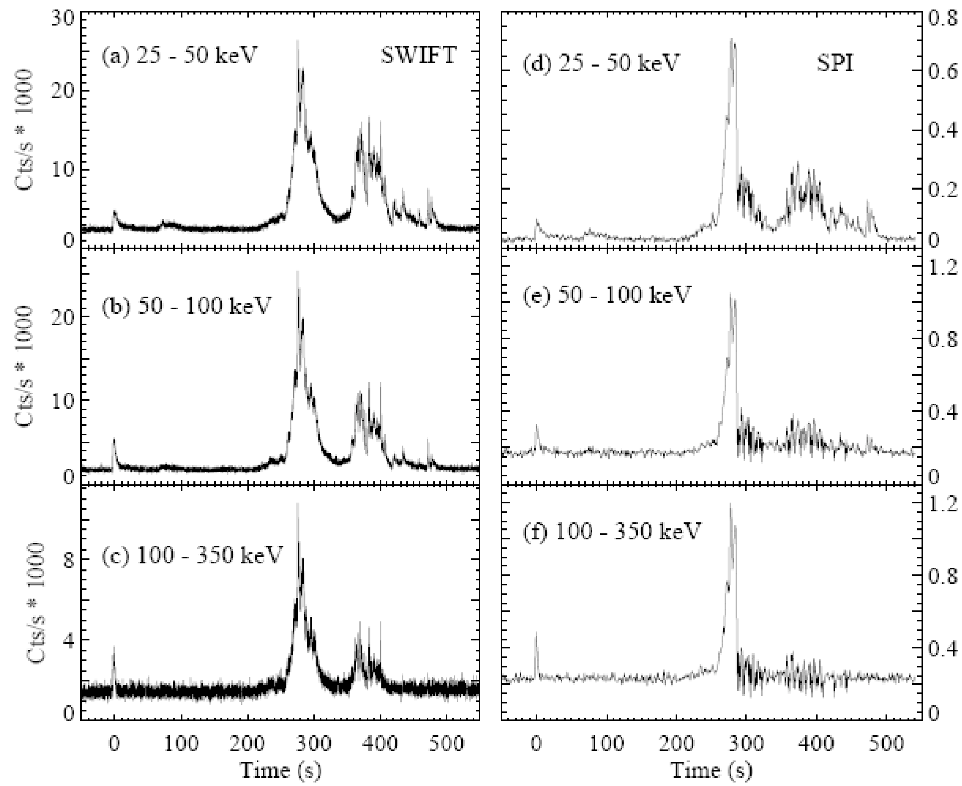
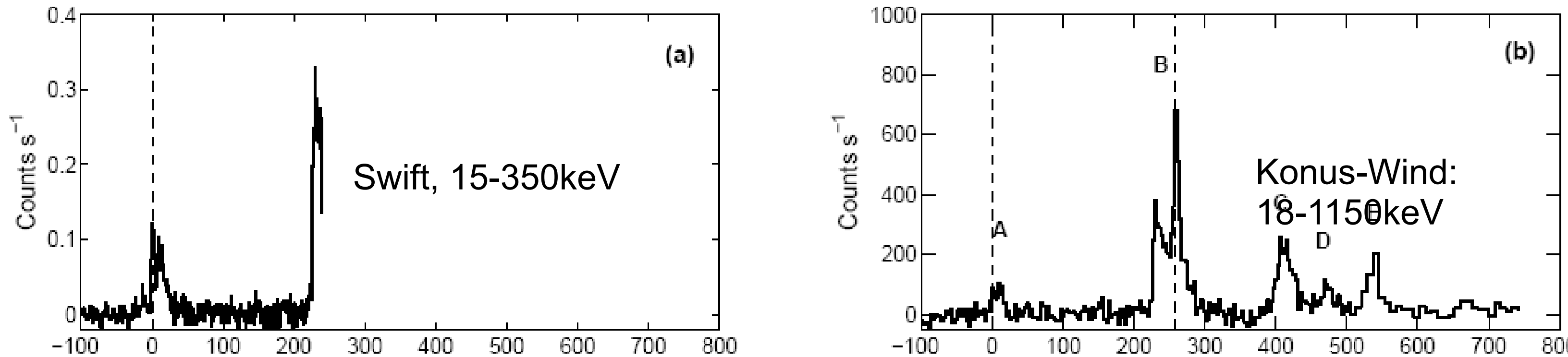


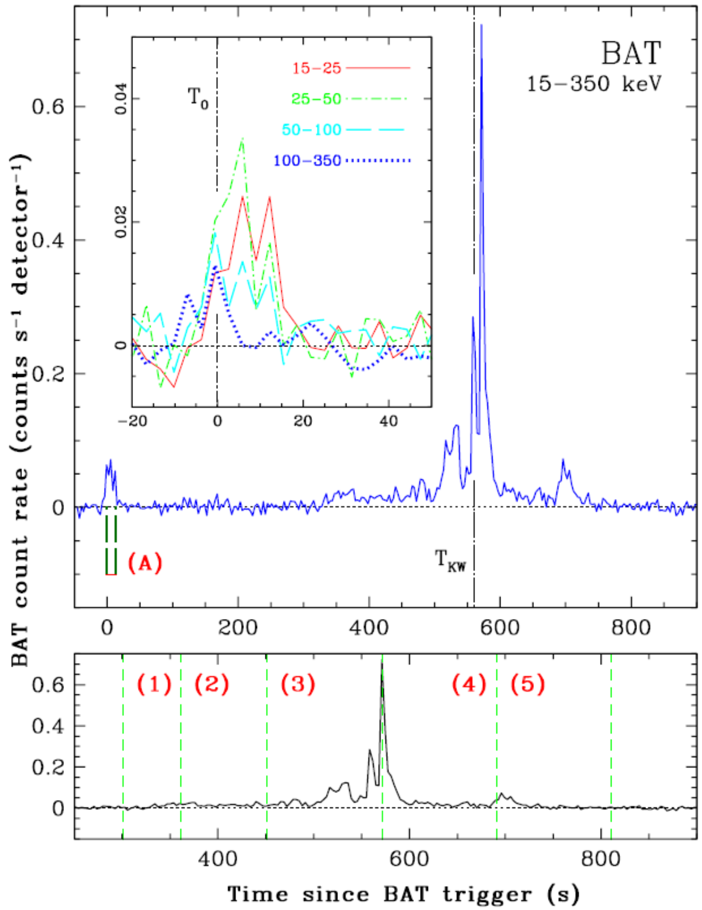
FIG. 1.— The *SWIFT* light curves of GRB 041219a in (a) 25–50 keV, (b) 50–100 keV and (c) 100-350 keV bands (Barthelmy et al. 2004), and the SPI light curves for the singles in the same bands in (d), (e), and (f) respectively. Times are relative to the peak of the precursor.

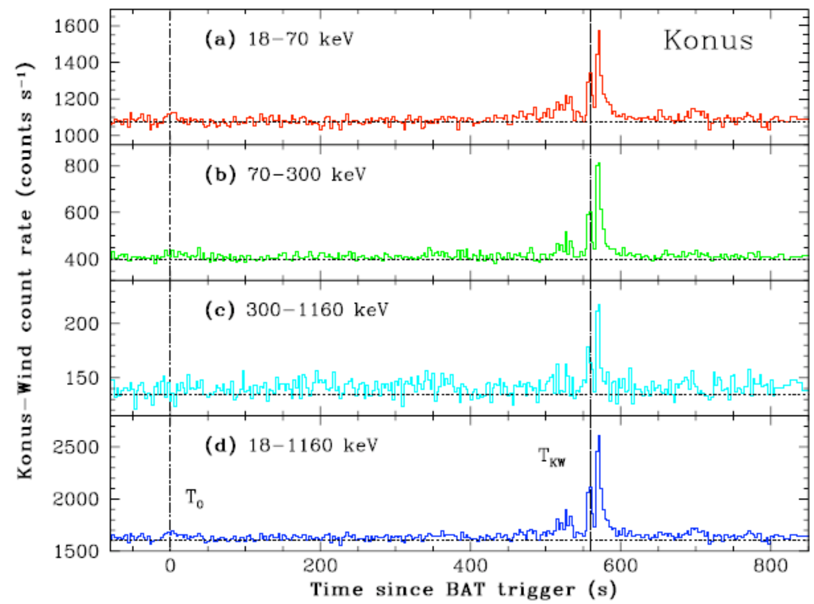
GRB050820A



Cenko et al. 2006

GRB060124





Romano et al. 2006

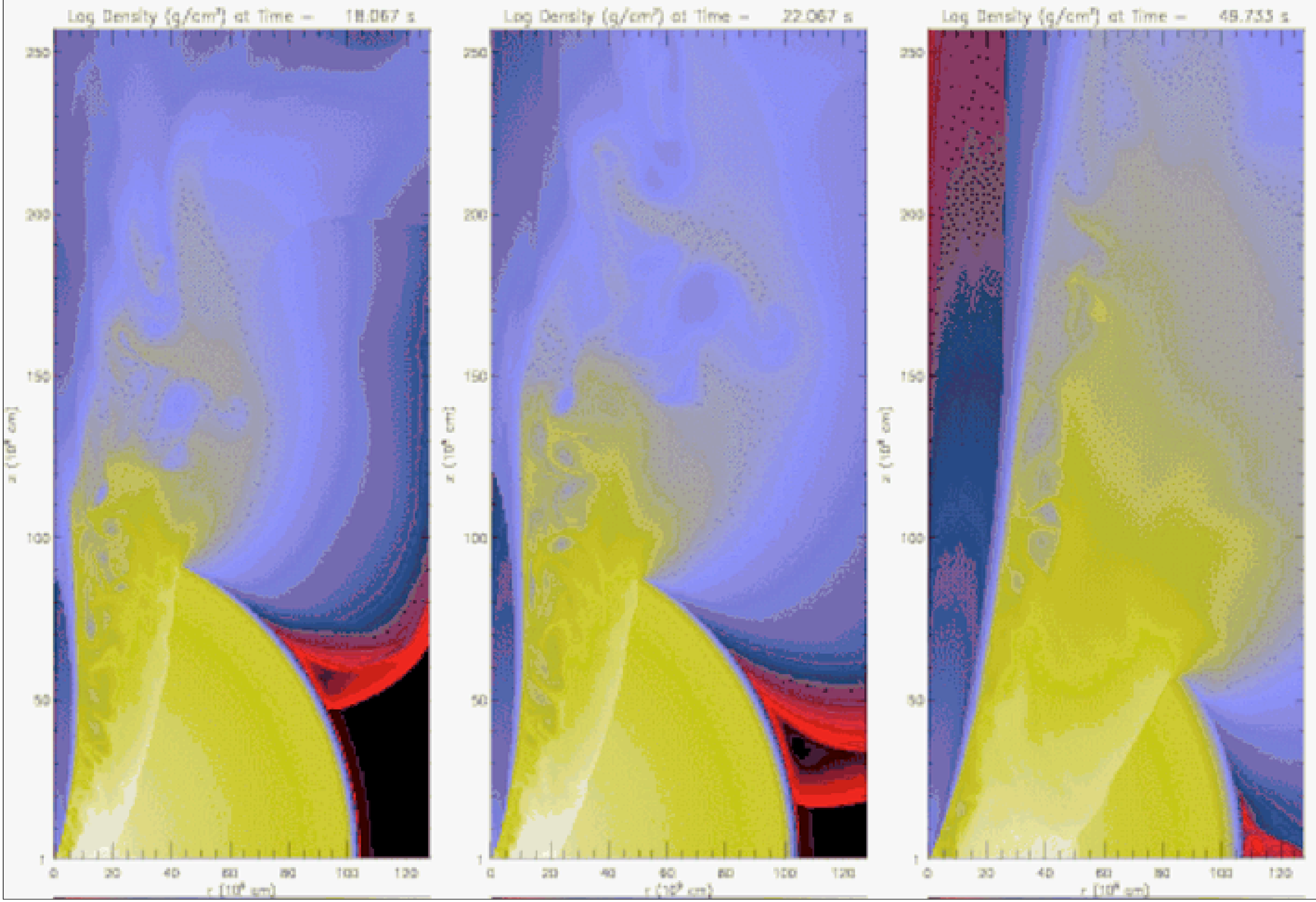
Precursor Interpretations

- Jet break-out from the progenitor envelope
  $\Rightarrow$ thermal precursor

  (e.g. Ramirez-Ruiz et al 02, Waxman-Mészáros 03, Morsony, Lazzati, Begelman 06)
- Fast jet before breaking out heats hot-spot above
- More promising is escape of “waste heat” cocoon surrounding fast jet - spreads over wider angle
- good candidate for gaps $t_{gap} \lesssim 10\text{-}20(1+z)$ s

  (roughly limited by ~ (R/c) times angular factors)

Jet & cocoon development, Morsony et al 07



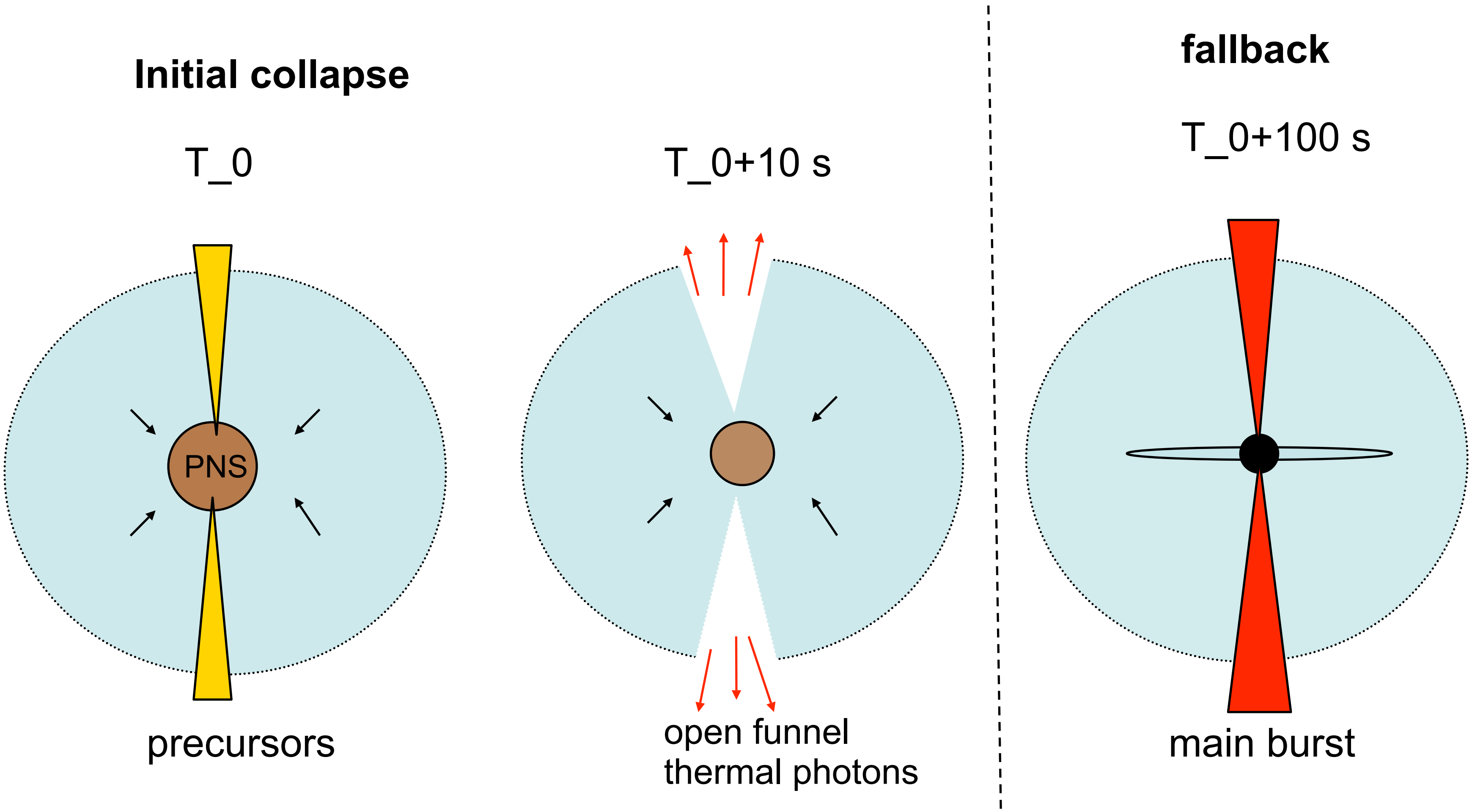
Longer precursor gaps

- Longer gaps ($t_{gap,obs} \gtrsim$ 50-100 s): may need a ***different mechanism***, not limited by geometrical time
- Such timescales reminiscent of ***dynamical times*** in early stage of core collapse in collapsar model of GRB, e.g. McFadyen & Woosley '99, Zhang et al 03
- In particular, "type II" collapsars, where initial collapse leads to initial ejection, followed by fallback, $\rightarrow$ ***delayed BH*** formation (50-100 s and up)

“Long-gap” Precursors:

- B) Propose ***fall-back collapsar*** (“type II”) scenario as likely candidate for t_{gap} > 50-100 s precursors (Wang-Mészáros, astro-ph/0702441)
- Assume initial core collapse leads to PNS, which leads to a supernova shock and a weak jet (e.g. from accretion on PNS, propeller mechanism, magnetar wind, etc) - ***weak jet ⇔ precursor***
- If precursor jet weak enough, do not disrupt envelope right away, fall-back of material leads to **PNS→ BH**, which then leads to ***main jet*** (collapsar GRB) , on numerically motivated timescale $t_{fallback} \gtrsim 100$ s

Precursor & Main burst



Wang & Meszaros 2007, astro-ph/0702441

Some SN-GRB Conjectures

- Rotation and jet-like structures may be common, and indeed may be dominant in the ccSN explosion (emerging theme from various recent simulations)
- The anisotropic semi-relativistic Γ~1 shocks, inferred from SN-GRB γ, XR, OUV lightcurves, may be driven or enhanced by such jets, by a cocoon, or by relativistic chocked jets
- The energy of semi-relativistic outflows inferred in SN/GRB is generally low, $E_{iso} \sim 10^{48}$-10^{50} erg
- Precursors appear similar, but larger Γ~10, hence expect less energy deposit in envelope, fallback

SN-GRB conjectures (cont.)

- So far, no conclusive evidence for highly relativistic jets in sub-energetic GRB/SN (except 030329); spectra are ≠, XRF or $\gamma-$rays compatible w. semi-relativistic jet
- Such semi-relativistic jets may be present even in usual high-z GRBs, but harder to detect, since weaker then relativistic jet.
- Total energy jet + SN may be ~constant, e.g.
  - strong jet $\rightarrow$ GRB + weak (or no) SN;
  - weak jet $\rightarrow$ weak (or no) GRB + strong SN
-